NEURO-OPHTHALMOLOGY
2016, VOL. 40, NO. 3, 113–119
http://dx.doi.org/10.3109/01658107.2016.1156707

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ORIGINAL ARTICLE

Static Subjective Visual Vertical in Healthy Volunteers: The Effects of Different Preset Angle Deviations and Test-Retest Variability

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ABSTRACT
The static subjective visual vertical (SVV) was assessed in 24 healthy volunteers with different preset angles (i.e., 10, 20, and 30 degrees), and in 20 other volunteers, the static SVV was tested and retested 1 week later. The static SVV results are influenced by the side of the preset angle (Wilcoxon test, $p \leq 0.001$), but not by the preset angle deviation. The test-retest static SVV outcomes are stable at a group level; however, they show statistically relevant variability at an individual level (−0.240 ≤ intraclass correlation coefficient [ICC] ≤ 0.508). A robust static SVV protocol is described in this paper.

ARTICLE HISTORY
Received 15 December 2015
Revised 7 February 2016
Accepted 17 February 2016

KEYWORDS
Otoliths; preset angle; subjective visual vertical (SVV); test-retest; variability

Introduction

Graviception is the perception of a person's orientation relative to the gravitational force, which can be measured by means of the subjective verticals. These subjective verticals can be divided into three tests, which are (a) the subjective visual vertical (SVV), (b) the subjective postural vertical (SPV), and (c) the subjective haptic vertical (SHV).[1] These graviceptive pathways integrate the vestibular, the visual, and the proprioceptive inputs and subsequently estimate the relative position of one's body with respect to the absolute vertical, namely, the gravitational field of the Earth.[2–4] The static SVV is an easily applicable test, which aims to detect otolithic imbalance and is a sensitive sign of brainstem dysfunction.[2] The static SVV is tested in complete darkness, in order for visual references to be excluded, and in an upright sitting position, so that proprioceptive inputs contribute only minimally. Therefore, the static SVV is almost exclusively determined by the otolithic function and balance, as these are the main receptors in the peripheral vestibular system sensitive to gravitational forces (i.e., linear accelerations), with the semicircular canals being predominantly sensitive to angular accelerations.[3]

Clinical static SVV testing is severely hampered by the lack of a uniform static SVV testing protocol, subsequently resulting in a marked heterogeneity concerning the SVV methodology in the literature. This makes generalization of the SVV findings in the literature very difficult. The main goal of this study is to further explore and propose a robust static SVV protocol, as was already studied in previous reports by Crevits et al.[5,6] We defined three aims concerning the SVV methodology and reliability to study in more detail.

The first aim of the present study was to measure the effects of different preset angle deviations on the final static SVV results in healthy volunteers. The second aim was to investigate the test-retest variability in a group of healthy volunteers, as this to our knowledge is unknown in the literature at this moment. We expected that the static SVV findings would not differ significantly at a group level, but that small variations would very likely exist at an individual level. Therefore, we estimated the size of these variations and the possible clinical relevance. The third aim was to further explore and propose a robust study protocol combining monocular and binocular static SVV measurements by using the method of adjustment.

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Methods

Study participants

From the neurological and clinical neurophysiological hospital staff 44 healthy volunteers were recruited, none of whom had a relevant medical history (they did not have neurological, otological, and/or ophthalmological diseases or complaints). All had a normal vision or their vision had been corrected to normal with contact lenses or glasses. Clinical neurological and neurotological examinations (i.e., clinical oculomotor examination, testing for a skew-deviation with the alternate cover, head-impulse, Dix-Hallpike, and supine roll tests) were normal in all healthy volunteers. The study was approved by the regional and local medical ethical committee (CMO Arnhem-Nijmegen, The Netherlands, number 2012/393), and all participants signed an informed consent.

Twenty-four participants (mean age: 27 years, range: 22–34 years; 9 men) were included in the study concerning different preset angle deviations and 20 other participants (mean age: 24 years, range: 21–32 years; 8 men) were included in the test-retest study.

Tests and procedure

Before measuring, the system was checked and if necessary adjusted to the absolute vertical with the aid of a plumb line. The subjects were sitting upright and 2 m away from a viewing screen, and we assured that both the (corrected) vision and the visual field of the subjects were sufficient to perform the test. The tests were performed in a totally darkened room to prevent visible landmarks from being seen, and the investigator operated the equipment in an adjacent room. Communication was possible by means of an intercom system. A laser-projected straight red line (1.6 m long and 5 mm wide) could be tilted and shown or taken away from a distance by the investigator (VERTITEST-II; Difra Instrumentation, Eupen, Belgium). The subject was instructed to adjust the laser-projected line to the gravitational vertical with a hand-held infrared remote controlled potentiometer (steps of 0.1 degree/click and with an angle speed of 3.85 degrees/second when the button was pressed continuously) and to wait for 5 seconds at the chosen end position to reconsider and thereafter to vocally confirm this definitive position. After this definitive confirmation, the line was taken away by the investigator and tilted to the new starting position before it was projected again to prevent the subject from being influenced. As a convention, deviations counter-clockwise from the absolute vertical were indicated by negative values and deviations clockwise from the absolute vertical were indicated by positive values. The deviations were measured with a precision of 0.1 degree.

For the first study aim, the static SVV was tested with different preset angle starting deviations. The investigator tilted the laser-projected red line at random to a preset angle that was either clockwise or counter-clockwise with a random starting deviation of 10, 20, or 30 degrees. Every starting deviation was tested four times so that a total of 12 measurements were obtained for every testing condition. The measurements were obtained under three different testing conditions in a random order: (i) both eyes viewing, (ii) right eye viewing, and (iii) left eye viewing. When all measurements in all the testing conditions were combined, a total of 36 static SVV results were obtained per subject. The lights were turned on for a few minutes after each viewing condition to check the head position and to prevent the SVV drift, resulting from being in the darkness for prolonged periods of time.[7]

For the second study aim, the static SVV was tested at baseline and 1 week later in the same subject to assess the test-retest variability. The investigator tilted the laser-projected red line at random to a preset angle that was either clockwise or counter-clockwise with an absolute starting deviation of 20 degrees. The measurements were taken twice so that four measurements were obtained for every testing condition, and measurements were also made for all the three testing conditions, as described above. Thus, a total of 12 static SVV results were obtained per assessment, and the test was repeated 1 week later. Also in this study, the lights were turned on for a few minutes after each viewing condition to check the head position and to prevent the SVV drift, resulting from being in the darkness for prolonged periods of time.[7]

For the third study aim, based on our findings of the observed variance between the methodologies of

Table 1. Results of the different preset angle deviations study.

Condition	10 degrees Mean (*SD*) [range]	20 degrees Mean (*SD*) [range]	30 degrees Mean (*SD*) [range]	*p* value (Friedman test)
Binocular (CW+CCW)	−0.4 (1.2) [−2.5–2.2]	−0.2 (1.3) [−2.3–3.4]	−0.2 (1.1) [−3.0–1.4]	0.236
OS (CW+CCW)	−0.2 (1.4) [−3.4–3.1]	−0.2 (1.7) [−3.0–4.0]	−0.4 (1.6) [−3.1–3.4]	0.243
OD (CW+CCW)	−0.2 (1.4) [−3.1–3.0]	−0.3 (1.5) [−2.9–2.6]	−0.2 (1.5) [−3.0–2.5]	0.989
CW (all conditions)	0.1 (1.3) [−2.1–3.0]	0.2 (1.4) [−2.1–4.3]	0.1 (1.5) [−2.7–4.0]	0.409
CCW (all conditions)	−0.6 (1.2) [−2.4–2.3]	−0.6 (1.3) [−2.9–2.6]	−0.6 (1.0) [−3.0–2.5]	0.620

Note. The mean deviation for every condition was given in degrees (with the standard deviation). CW = clockwise starting deviations; CCW = counter-clockwise starting deviations; OS = oculus sinister; OD = oculus dexter; *SD* = standard deviation.

prior studies, we explored and constructed a robust SVV study protocol, mainly to improve observer variation and to make the test results suitable for comparison among different laboratories.

Statistical analysis

Because of the non-parametrical distribution of the three dependent groups concerning the different angle preset deviations study (i.e., 10, 20, and 30 degrees), the Friedman test for repeated-measures analysis of variance by ranks was applied for comparison. Concerning the two non-parametrically distributed and dependent groups in the test-retest study, the Wilcoxon test was applied for comparison.

Additionally, the test-retest reliability was assessed by the intraclass correlation coefficient (ICC); a two-way random-effect model with absolute agreement and average measures was used for analysis. The following ICC ranking was adopted: ICC values above 0.75 represent excellent reliability, values between 0.4 and 0.75 represent fair-to-good reliability, and values below 0.4 represent poor reliability. The intraclass correlation coefficient is considered to be the key statistical indicator of relative reliability. The statistical database software SPSS version 23.0 (IBM, Armonk, NY, USA) was used for statistical analyses.

Results

Table 1 shows the results of the different preset angle deviations study. The Friedman test for repeated-measures analysis of variance by ranks showed a p value <0.001 for all binocular and monocular measurements in all different deviations (i.e., 10, 20, and 30 degrees) combined, meaning that some groups differed significantly. We subsequently ran a series of bivariate comparisons (Friedman test) for further analysis between the three groups themselves in different deviations (i.e., 10, 20, and 30 degrees). The binocular and monocular measurements between the different deviations did not differ significantly according to the Friedman test. The combined clockwise preset angle measurements, which were taken from the three conditions (i.e., binocular and monocular viewing conditions), did not differ significantly either between the different deviations, according to the Friedman test. The same was true for the combined counter-clockwise preset angle measurements.

There was, however, a statistically significant difference between the static SVV results of the combined clockwise preset angle measurements in comparison with the combined counter-clockwise measurements at all deviations separately and combined according to the Wilcoxon test (see Table 2). The same was true for the test-retest measurements in the second part of the study ($p = 0.005$ for the first measurements, and $p = 0.002$ for the retest measurements, according to the Wilcoxon test).

Table 3 shows the results of test-retest study. At a group level, there was no statistically significant difference between the test and retest measurements, according to the Wilcoxon test. Also, the individual absolute mean differences and standard deviations were calculated for all volunteers, which were defined as: $|\Delta| = |SVV^{first\ test} - SVV^{retest}|$. However, at the individual level, the test-retest reliability according to the ICC was poor overall.

Discussion

The first aim of our study was to assess the influence of different preset angle starting deviations (i.e., 10, 20, and 30 degrees) on the final static SVV outcomes. We found a statistically significant difference concerning the side of the preset angle

Table 2. Data concerning the clockwise starting deviations of all conditions in comparison with the counter-clockwise starting deviations of all conditions.

Condition	10 degrees Mean (*SD*)	20 degrees Mean (*SD*)	30 degrees Mean (*SD*)	All deviations combined
CW (all conditions)	0.1 (1.3)	0.2 (1.4)	0.1 (1.5)	0.1 (1.4)
CCW (all conditions)	−0.6 (1.2)	−0.6 (1.3)	−0.6 (1.0)	−0.6 (1.2)
p value (Wilcoxon test)	<0.001*	<0.001*	0.001*	<0.001*

Note. CW = clockwise starting deviations; CCW = counter-clockwise starting deviations; *SD* = standard deviation.
*Statistically significant differences with a *p* value <0.05.

Table 3. Test-retest study.

Condition	First test Mean (*SD*) [range]	Retest Mean (*SD*) [range]	Absolute Individual difference between tests Mean (*SD*) [range]	*p* value Wilcoxon test	Intraclass correlation coefficient
Binocular (CW+CCW)	−0.6 (1.1) [−2.7–1.5]	−0.5 (1.1) [−2.3–1.6]	1.2 (1.0) [0–3.2]	0.705	−0.095
OS (CW+CCW)	−0.1 (1.2) [−1.9–2.0]	−0.3 (1.8) [−3.0–2.2]	1.4 (1.1) [0–3.6]	0.395	0.508
OD (CW+CCW)	−0.4 (1.9) [−3.1–3.0]	−0.5 (1.7) [−2.9–2.4]	2.0 (1.6) [0–5.2]	0.896	−0.240
CW (all conditions)	−0.8 (1.3) [−2.4–2.6]	−0.9 (1.2) [−2.7–2.5]	1.2 (1.1) [0–3.4]	0.601	0.234
CCW (all conditions)	0 (1.4) [−3.5–1.1]	−0.1 (1.6) [−2.7–1.5]	1.5 (1.2) [0–3.9]	0.507	0.251

Note. CW = clockwise starting deviations; CCW = counter-clockwise starting deviations; OS = oculus sinister; OD = oculus dexter; *SD* = standard deviation. The mean deviation for test was given in degrees (with standard deviation). Also, the absolute individual differences between the test and the retest were given (with the standard deviation) [and range, mean ± 2× standard deviations].

(clockwise or counter-clockwise) in relation to the static SVV outcomes, with the static SVV measurements shifting towards the side of the preset angle. However, this SVV shift did not increase with increasing preset angle deviations, since the influence of the 10 degrees preset angle starting deviation was the same as in the 20 and 30 degrees deviations. This is in concordance with the previously published papers by Pagarkar et al.[8] and Baccini et al.[1]; both noted that the static SVV results were biased in the direction of the preset angle. Baccini et al.[1] also tested the static SVV at different preset angle deviations (i.e., 1, 2, 4, 8, and 12 degrees according to the adjustment [ADJ] method) and concluded that the bias was more pronounced at higher deviations, without significant differences between 8 and 12 degrees of deviation. The authors speculated that deviations greater than 8 to 12 degrees do not result in a more pronounced bias of the final static SVV result. However, the methodology of their study in comparison with ours is markedly different, as we tested preset angle deviations with greater deviations and we also included monocular measurements besides the binocular measurements. We confirm the hypothesis of Baccini et al.[1] that preset angle starting deviations greater than 12 degrees do not have an additional effect on the static SVV shift.

A few explanations for the shift of the static SVV towards the side of the preset angle have been proposed so far. The first explanation is the entrainment effect proposed and studied by Mezey et al.[9] The entrainment effect states that a rotating environment in the roll plane, but also a rotating line, causes a torsional movement of the eyes in the same direction as the rotation itself. They concluded that this is a kind of optokinesis, which, however, could not be classified as an optokinetic nystagmus, since the mean decay time of this effect is about 1 second after cessation of the stimulus and is therefore too slow. This effect is predominantly active in the last 10 degrees of the rotating stimulus in reference to the absolute vertical. Surprisingly, it is not significantly influenced by the presence of a visible non-rotating background. The entrainment effect is present when the laser-projected line is both actively or passively rotated. Mezey et al.[9] stated that the otoliths have a dampening influence on this entrainment effect; therefore, patients with a disturbed vestibular function have an increased visual reliance, and this in combination with the lowered dampening effect results in an increased entrainment effect, and secondarily possibly resulting in greater static SVV deviations. This could be the reason why preset angle deviations greater than 8 to 12 degrees do not result in a greater deviation of the static SVV towards the preset angle. In our opinion, however, there is one major problem with this explanation; the subjects in our study were instructed to reconsider their final line adjustments for 5 seconds after rotating before approving. In this period, the line stood still and was not rotated. The entrainment effect could not play a significant part during this period of reconsideration, since the decay time of this effect is only 1 second. Therefore, the ocular torsion had normalized during the time of reconsideration and the volunteers were, at that moment, still able to change the rotation of the line.

The second explanation is the uncertainty theory,[1] which states that volunteers rotate the line towards the point at which they are uncertain whether the perceived line is already vertical. This uncertainty range is variable between healthy persons and extends from clockwise to counter-clockwise and also encloses the absolute vertical. Most people stop rotating the line when they have just entered this uncertainty range and mostly without further rotation, until the moment that they perceive the line as directing towards the opposite side, before readjusting the line to their subjective vertical. We support Baccini et al.[1] that the uncertainty theory in combination with the entrainment effect is the most likely explanation for the static SVV bias towards the preset angle. We hypothesize that the subject is at first biased by the entrainment effect, which could possibly increase the subject's uncertainty range during rotation, and is then possibly hesitant to second-guess his or her first choice when the entrainment effect subsides. However, we have to state that the hypothesis above is purely speculative and we do not have definitive proof for confirmation.

A tilt in the static SVV could also be induced by tilting the head and/or the body. The E-effect was first described by Muller in 1916; a moderate lateral tilt of the head resulted in a tilt of the static SVV to the contralateral side. A more outspoken lateral tilt of the head and/or the body resulted in a static SVV tilt to the ipsilateral side. This effect is called the A-effect and was first described by Aubert in 1861.[4] Both effects are thought to be somatosensory in origin. In our study, the subjects sat upright in a vertical position in front of the viewing screen and the position was regularly checked during and between the measurements, so we do not believe that either the E-effect or the A-effect can explain our findings.

The second aim of our study was to assess the test-retest variability of the static SVV results. Our study could not demonstrate a significant difference of the static SVV results at a group level between the measurements. However, when the individual absolute differences were calculated, a variation could be seen. For instance, the absolute variation could be up to 3.2 degrees for binocular viewing, up to 5.2 degrees for monocular viewing, and up to 3.9 degrees for all conditions starting with the counter-clockwise preset angle. This was supported by the overall poor test-retest ICC results. To our knowledge, we are the first to note this individual static SVV test-retest variation. Tesio et al.[10] also calculated the static SVV test-retest reliability showing excellent reliability in young healthy volunteers and fair to good reliability in older volunteers (ICC values were respectively 0.84 and 0.48). However, the study of Tesio et al.[10] has some important differences in comparison with our study, (a) our study was performed in a totally darkened room to prevent visual references from biasing the static SVV results, whereas Tesio et al. performed their study in a dim-light surrounding; (b) the preset angle deviation in our study was greater in comparison with the study of Tesio et al. (respectively 20 and 2.8 degrees), and from the results of Baccini et al.,[1] one can conclude that greater preset angle deviations will result in greater static SVV deviations (with a maximum of 8 degrees); and (c) the volunteers in our study used a remote control to manually rotate the laser line, whereas the volunteers in the study by Tesio et al. only had vocal control over the line rotations (rotations were performed manually by a technician), possibly influencing the amount of ocular torsion.

A limitation of our study is that we only studied the test-retest variability in a group of a relatively young age, and not in other groups, especially of a more advanced age. Baccini et al.[1] demonstrated that the static SVV measurements were age dependent, and that older persons had more difficulty in judging the absolute vertical, resulting in higher

Table 4. Static subjective visual vertical testing protocol. Preset angle of 20 degrees (clockwise and counterclockwise).

Binocular measurements		
	First measurement	Second measurement
Clockwise preset angle	*B1*	*B2*
Counter clockwise preset angle	*B3*	*B4*
Monocular measurements (Oculus Sinister viewing)		
	First measurement	Second measurement
Clockwise preset angle	*L1*	*L2*
Counter clockwise preset angle	*L3*	*L4*
Monocular measurements (Oculus Dexter viewing)		
	First measurement	Second measurement
Clockwise preset angle	*R1*	*R2*
Counter clockwise preset angle	*R3*	*R4*
Results		
Mean binocular deviation	*Mean (B1, B2, B3, B4)*	
Mean monocular oculus sinister viewing deviation	*Mean (L1, L2, L3, L4)*	
Mean monocular oculus dexter viewing deviation	*Mean (R1,R2, R3, R4)*	
Mean clockwise deviation	*Mean (B1, B2, L1, L2, R1, R2)*	
Mean counter-clockwise deviation	*Mean (B3, B4, L3, L4, R3, R4)*	

deviations away from the true vertical at higher preset angle deviations (i.e., 8 and 12 degrees). We started our study before the publication of Baccini et al.[1]; therefore, we were not able to look for the older age group. The second limitation is the rather small size of the group of healthy volunteers. The third and last aim of our study was to explore and propose a robust static SVV study protocol; we refer to Methods and Table 4 for details. The static SVV is a psychophysical test, which can be measured by two methods. The most commonly used method is the adjustment method (ADJ), also known as the method of average error.[1] However, recently, Baccini et al.[1] extensively tested the static SVV by means of the two-alternative forced choice method (2AFC) in comparison with the ADJ. They concluded that the two testing methods were equally reliable, but that the 2AFC method was, in their opinion, easier to perform and therefore more practical to use. The main problem concerning static SVV testing, at this moment, is the lack of a uniform testing protocol, resulting in a marked heterogeneity in the testing procedures across the different studies. Therefore, the different study results cannot be easily generalized to the everyday clinical practice, and furthermore, a few methodological issues still need to be addressed. The present study was started before the publication of the article by Baccini et al.[1]; however, we feel that our study both supports and complements their findings, as was described earlier. We would like to refer to Methods and to prior papers by Crevits et al.[5,6] for a detailed overview concerning our proposed SVV protocol. The main advantage of this approach is that both binocular and monocular assessments are systematically made, which may give insight into the nature of the static SVV deviations. For instance, patients with an ocular tilt reaction secondarily resulting from a brainstem infarction are very likely to show an SVV tilt in at least two static SVV conditions, including the binocular viewing condition.[2] Patients with a monocular torsion secondarily resulting from an isolated oblique or vertical ocular motor palsy are very likely to show an abnormal static SVV under ipsilateral monocular viewing conditions, but the other monocular and binocular viewing conditions are expected to be normal.[5,6] The proposed study protocol is robust and incorporates 12 static SVV measurements per subject, which can be easily performed clinically in 15–20 minutes and which requires only minimal instrumentation.

The reference values for the static SVV testing according to our own normative data by using the protocol discussed above are (a) for binocular measurements: $-3.0 \leq x \leq +3.0$ degrees; b) for monocular measurements: $-3.5 \leq x \leq +3.5$ degrees; c) for counter-clockwise measurements combined: $-5.0 \leq x \leq +2.0$ degrees; and d) for clockwise measurements combined: $-2.0 \leq x \leq +5.0$ degrees. However, we advise all laboratories to obtain their own reference values in different age groups, as the results of the static SVV are age dependent.[1]

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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